THE BIG-BANG THEORY

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Newton's work gave a mathematical basis for the universe on a large scale. However, the data available at the time suggested a static unchanging universe. This could not easily be explained in the context of the law of gravitation, since all bodies in the universe attract all other bodies with the force of gravity. Newton realized that there was only one solution to this problem: in a static universe, matter had to be uniformly spread throughout an infinitely large space. In 1826, Heinrich Olbers published a paper containing what is known as *Olbers' paradox; such a universe would lead to a perpetually bright sky on earth.

Space–time

Cosmologists now believe that Newton's model was based on incorrect assumptions about the structure of space, time, and matter. Einstein in his general theory of *relativity (1915) proposed that the universe exists in four-dimensional space–time. This space–time is curved by the presence of matter, and the matter moves by following the resulting curves.

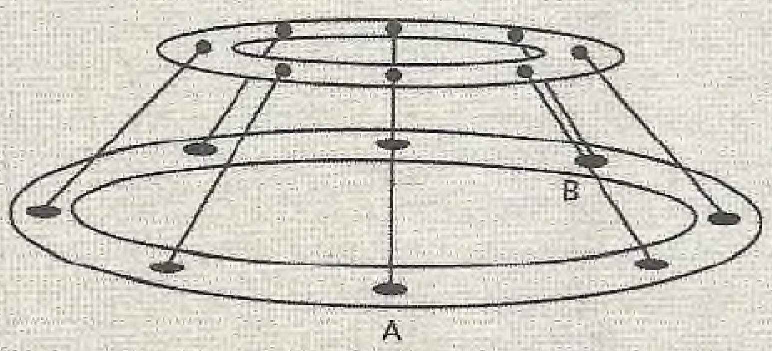
The expanding universe

The discovery by Hubble in 1929 that the universe is expanding provided a starting point for the ideas on which our present understanding of the universe is based. Hubble made his discovery by analysing the *spectra of light from distant galaxies and noting a persistent *red shift, which he explained in terms of the *Doppler effect; an increase in observed wavelengths of light occurs because the light source is receding from the observer. The larger the speed, of recession, the larger the red shifts. Hubble discovered a pattern in his data: the further away the galaxy, the greater the speed of recession. Known as *Hubble's law, this provided the evidence that the universe is expanding and a resolution to Olbers' paradox. If the galaxies and the earth are moving apart, the radiation falling on the earth from the galaxies is reduced. The further galaxies are away from the earth, the smaller their contribution to the radiation falling on the earth.

This model might seem to place the earth at the centre of the universe again. However, it is space itself that is expanding and the galaxies are imbedded in this space. The ring (space) in the diagram has dots (the galaxies). The expansion of the ring means that the view from any one dot is that the other dots are receding at a speed proportional to their distance away. No single dot is at the centre of the system but all dots see the same thing.

Age of the universe

Hubble's law may be stated in the form: $H_0 = v/d$, where v is the speed of recession of the galaxy, d is the earth–galaxy distance, and H_0 is called the



The expansion leads to the recession of B from A along the ring. The speed of recession will be directly proportional to the distance of B from A along the ring.

Hubble constant. Assuming that the galaxies have always been moving apart, the age of the universe (*T*) can be estimated, i.e. $T = 1/H_0$. On this basis the age of the universe would be between 15–18 billion years.

The origin of the universe

This view of the origin of the universe is called the **big-bang theory**. The theory suggests that the universe originated as a minute but very hot body and that the temperature has been falling as the expansion has continued. In 1945 George Gamow predicted that there should be a *microwave background corresponding to a black-body temperature a few degrees above absolute zero. This microwave background was discovered 20 years later. The big-bang theory also explains the amount of helium in the universe.

In 1992, the COBE satellite discovered that there were very small variations in the microwave background. This discovery helped to explain why the universe formed into galaxies and stars. The non-uniformities that began the nucleation of galactic matter in the early universe now appear as the small variations in the microwave background.

Fundamental forces

It is thought that the four *fundamental interactions in the universe are all manifestations of the same force. This force existed when the big bang, occurred at a temperature above 10^{15}K. As the universe cooled the forces separated as the original symmetries were broken. Gravity was the first to separate, followed by the strong nuclear force, and the weak and electromagnetic forces (see table).

Time from big bang	Temperature (K)	State of the universe/forces
0 second	infinite	The universe is infinitesimally small and infinitely dense (i.e. a mathematical singularity).
10^{-12} second	10^{15}	Weak and electromagnetic forces begin to separate.
10^{-6} second	10^{14}	Quarks and leptons begin to form.
10^{-3} second	10^{12}	Quarks form the hadrons; quark confinement begins.
10^{2} second	10^{7}	Helium nuclei formed by fusion.
10^{5} years	10^{4}	Atomic era; atoms form as protons combine with electrons.
10^{6} years	10^{3}	Matter undergoes gravitational collapse.
$.5–1.8 \times 10^{10}$ years	2.7	Present day: cosmic background corresponds to about 2.7K.

The future

Research into the future of the universe is clearly speculative. Whether the universe will continue to expand indefinitely depends on its mean density. Below a critical level (the critical density), gravitational attraction will not be enough to stop the expansion. However, if the mean density is above the critical density the universe is **bound** and an eventual contraction will occur resulting in a **big crunch**. This may precede another big bang initiating the whole cycle again.